Final synopsis of the thesis entitled

Spatio-Temporal Distribution, Biology and Stock Status of the Longtail Tuna *Thunnus tonggol* (Bleeker, 1851) Commercially Exploited off Gujarat, North West Coast Of India

by

K. Mohammed Koya

In fulfillment of the requirement for the award of

Doctor of philosophy
in
Biosciences

Under the guidance of

Dr. (Mrs) **Pratibha Rohit,** Principal Scientist,

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
P.B.No.1603, Kochi, Kerala- 682018

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Spatio-Temporal Distribution, Biology and Stock Status of the Longtail Tuna *Thunnus tonggol* (Bleeker, 1851) Commercially Exploited off Gujarat, North West Coast Of India

Introduction

Thunnus tonggol (Bleeker, 1851), commonly known as longtail tuna is one of the neritic tunas, distributed throughout the Indo-West Pacific region, extending from the coast of Somalia, Gulf of Aden, Red Sea of Japan, Papua New Guinea, Australia, and New Zealand. This species due to its good meat texture is commercially very valuable and is exploited by a variety of gears such as purse seine, gill net and lines. In South China Sea where the species is found abundantly, exploitation is by all the above gears whereas in the Northern Arabian Sea (AS), longtail is exploited mainly by the gillnets followed by the troll line to a lesser extent. The species enjoys a wide distribution along the coast of India including the Andaman and Nicobar Islands. It forms a good fishery along the west coast of India with major abundance in the North West coast comprising of Gujarat and Maharashtra.

Tunas constitute nearly 2% of the total marine fish production in Gujarat (2012) with the longtail tuna contributing nearly 50% of the total tuna catch. A fleet of gillnetters with varying sizes and operating off Gujarat target these resources. In India, the longtail tuna fishery is almost exclusively by drift gillnets and contribution by all other gears such as long lines, troll lines and purse seine are negligible. An export trade for the longtail tuna exists in India which is mainly based on the catch landed at Veraval, Mangrol and Porbander fishing harbours in Gujarat. They are mainly exported as whole frozen or in gilled and gutted form.

Information available on the biology, growth, movement and population structure of longtail tuna are limited globally. Information on these aspects is sparse from the northwest coast of India where it forms a considerable fishery. Hence, the study focused on collating the available information on the species at global, regional, national and state levels and filling the key knowledge gaps with respect to fishery, movement, biology, stock structure and stock status. The study revealed the distributional extent of the longtail tuna fishery along the coast of Gujarat, ecological footprints of the gillnet fishery for tunas, spatio-temporal movement of the species, biological information including length-weight relationship, its feeding and reproductive behaviour; population parameters, stock structure and the status of exploitation along the west coast of India. The study brings in new information on the basic biology, distribution, ecology and stock structure of the species from the region and update on its fishery and stock status.

Scope, Objectives, Area and Period of the study

Scope of study

Fisheries, with a global production of 171million tonnes is a USD 362 billion industry; engaging nearly 60 million people and fish accounted for 17% of the animal protein consumed by the global population (FA0, 2018). The world capture fisheries production is projected to increase slightly by 2030 only if the resources are managed properly (FAO, 2018).Several international conventions such as United Nations Sustainable Development Goal (SDG), Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD) etc. stresses upon management of the fisheries resources following science based management plans in order to maximise the benefits sustainably. The National Policy on Marine Fisheries, 2017 (NPMF, 2017) of the Govt. of India urges for bringing in management interventions including development of species-specific and area-specific management plans in order to realise the full potential of marine fisheries of the country.

Data limitations have often been regarded as one of the greatest obstacles to science-based management of the complex ecosystems (Burgess, *et al.,* 2018). Unimpeded flow of scientific information is a necessity for the development of sound fisheries management plans. Longtail tuna is a commercially and ecologically important species of tuna inhabiting the neritic realms of coasts of the Indo-Pacific; and along the coasts of India, its dominance is more in the north-west coast. Despite its importance to commercial fisheries, little is known about its biology, stock status and structure, distribution and habitat throughout its distributional area, especially the north eastern Arabian Sea, where the species forms a considerable fishery. The species has also been categorised as data deficient in the latest assessment by the International Union for Conservations of Nature (IUCN) (Collette *et al*., 2011).This study therefore will help to fill the knowledge gaps in fishery, spatial distribution, ecology, biology, stock structure and stock status of the species from the north-west coast of India, thereby contributing to sustainable exploitation of the resource in the northern Arabian Sea region.

Objectives

i. To study the fishery, spatio-temporal distribution and habitat of the longtail tuna off the coast of Gujarat.
ii. To study the biology and population dynamism of the longtail tuna caught off Gujarat, north west coast of India
iii. To study the interaction of non-target species in the gillnet tuna fisheries, influence of depth and time of fishing on the interaction; and understand the management implications.
iv. To study the stock structure of longtail tuna and the status of exploitation of the stock off Gujarat for evolving management options.

Area and period of study

The study area is the north-eastern Arabian Sea off the state of Gujarat, north-west coast of India. It is a major maritime state with a coastline of nearly 1600km (20^{o}08'N to 23^{o}40'N) and continental shelf area of 184000sq.km constituting nearly 50% of the shelf area along the west coast of India and nearly 35% of that of entire India. With landing of 7.74 lakh tons, the State ranked first in the marine fish landing of India during 2016.

Primary data on catch and effort, spatio-temporal movement, length-frequency, reproductive and feeding biology and stock structure were collected during January, 2013 to December, 2016. Historic, time series data of catch and effort of the species since 1985 to 2017 was used for studying the historic trends. The nominal catch data of countries in the region, downloaded from the Indian Ocean Tuna Commission (IOTC) database for the period 2006-15 was used for related studies.

The thesis has been organised into six chapters each focussing on the major areas /objective of the study. The synopsis comprises of very brief introduction of the chapter, methodology and results and discussion. The graphical presentations of the results are limited to very few salient finding in this document.

Chapter 1: General Introduction and Review of Literature.

A brief introduction on the area of study has been provided in the beginning. Literature review is provided below in sequential order of the chapters.

Fishery, spatial distribution and habitat of longtail tuna.

Longtail tuna, *Thunnus tonggol* (Bleeker, 1851) has an exceptional pattern of distribution and standing in tuna fisheries globally. Its distribution is limited to the tropical belt in the northern hemisphere along the Indo-West Pacific from Japan through the Philippines to Papua New Guinea to northern Australia, west through the East Indies, India, Middle East Asia up to the horn of Africa (Collette and Nauen, 1983). Though nearly 17 countries in the Indo-Pacific exploit the resource (Yesaki, 1994), it forms a relatively significant component of tuna fisheries in only few countries. It is known that the longtail is an epipelagic fish occupying neritic realms except very turbid waters and areas with reduced salinity (Collete, B.B. and Nauen, C.E., 1983), however, detailed information on its preferred ranges of environmental parameters are not fully known.

Intricacies of variations in fishery performance among the regions and different sub-regions are not fully known (Griffiths *et al*., 2010a). Though the northern Arabian Sea is the second most important region in terms of commercial fishery, there is substantial difference in its exploitation among the countries in the region in terms of quantity, pattern of exploitation, scale of operation, *etc*. (Yesaki, 1994). The IOTC (IOTC, 2017a) notified the stock to be both overfished and subject to overfishing as per 2015 data and emphasized the need for

collecting/collating additional information on the fisheries, catch rates, size composition, life history traits, *etc.* by the CPCs.

Biology of Longtail tuna

Information on the reproductive biology of this species in the NE Arabia Sea is limited to the studies by Abdussamad *et al*. (2012a), Kaymaran *et al.* (2011) and Hedayatifard (2007). Abdussamad *et al.* (2012b) provided a pan India account of the fishery and biology of longtail tuna. However, emphasis on the fishery of the north-west coast, where the longtail tuna enjoys a considerable fishery was little. Quantitative account of feeding ecology of the longtail tuna is scanty from the North-East Arabian Sea as well. The available information on the diet of the species is limited to those by Silas (1967) from the south east coast of India, Wilson (1981b) from Gulf of Papua, Serventy (1942, 1956) and Griffiths *et al.* (2007) from Australia and Abdussamad *et al*. (2012) from, India.

Non-tuna species interaction in gillnet tuna fisheries

Gillnet is the major tuna fishing gear (33%) in the entire Indian Ocean followed by purse seines (26%) (Miller *et al*., 2017), contributing nearly 53% of the artisanal nominal catches reported to the IOTC (IOTC, 2017c). Tuna fishing in India is of artisanal nature, with the total annual landing of 0.92 lakh tonnes in 2016. The catch is predominated by neritic tunas comprising 64% of total tuna catch (CMFRI, 2017). Gillnets world over are regarded as one of the major fishing gears catching non-target resources posing great concern for fisheries management. Small scale fisheries in the Indian Ocean region have landed 1, 90,000 tonnes of non-tuna species for 1, 40,000 tonnes of tuna caught annually in the recent years (Gillet, 2011).

Stock structure and stock status

There have been a wider debate on the stock structure of *Thunnus tonggol* (Bleeker, 1851) in the Indo-Pacific mainly based on the meristic and morphometric (Serventy, 1956; Silas, 1967; and Wilson 1981b) and electrophoretic (Lewis, 1981) studies which postulated numerous stocks (self-sustaining units) throughout the distributional range of the species. IOTC, the Regional Fisheries Management organization (RFMO) monitoring and managing the fisheries for tuna in the Indian Ocean urged (IOTC, 2017a) for concerted efforts from the CPCs for stock delineation using molecular techniques. The IOTC reported the status of the stock to be overfished and subject to overfishing (IOTC, 2017a). Few studies hinted on the stock structure of the species in the Indian Ocean (Kunal, *et al.*, 2014) and South China Sea (Willette *et al.,* 2016) using genetic studies.

Stock status of Longtail tuna

Recent information on the population parameters and stock assessment of the longtail tuna in India has been limited to the works by Ghosh *et al.* (2010), Abdussamad *et al*. (2012a) and Vinod *et al*. (2017). However, there has not been any exclusive study on the population

dynamics and stock status of longtail tuna in its major ground, the north-west coast of India. There have been few studies on the population dynamics and stock assessment of longtail tuna elsewhere in the world. The recent ones being that by Kaymaran *et al. (*2013) for the Persian Gulf and Oman Sea, Ahmed *et al.* (2016) for the Arabian Sea off Pakistan, Hassadee *et al*. (2014) for Gulf of Thailand, Hassadee *et al*. (2014) for Andaman Sea and Griffiths *et al.* (2010a,b) for the Australian waters. Basin scale assessment of the stock of the longtail tuna in the Indian Ocean have been limited to few assessments based on data poor methods as suggested by Zhou and Sharma (2013, 2014) and Martin and Sharma (2015). The IOTC (2016) recently updated the stock status of LOT using Catch-MSY and Optimised Catch Only Methods (OCOM) (Zhou *et al*., 2013) methods.

Chapter 2: Fishery, spatial distribution and habitat of longtail tuna along the coast of Gujarat.

The chapter describes the fishery of the species in the northern Arabian Sea region during 1996-2017 and describes the trend and contributions of different countries in the region *vis-à-vis* the continental shelf area in their possession. The longtail tuna fishery in India in general and Gujarat in particular was studied using time series data from 1985 to 2017 for the trend and contributions by different states/region, seasonal variations in catches, crafts and gears involved and size composition in the fishery with seasonal variations. Under the spatial studies, the spatial variations in longtail tuna fisheries off Gujarat with details on seasonal variations in abundance areas and variations with respect to ontogenetic stages was analysed. Influence of oceanographic parameters like the sea surface temperature and chlorophyll on the movement of the fishes have been detailed and the preferred ranges of the environmental parameters arrived at.

Materials and Methods

Collection of Catch and Effort Data:

Data for the regional analysis was collected from the Indian Ocean Tuna Commission (IOTC) (http://www.iotc.org/data-and-statistics accessed on 15, January, 2018) (2007-2016 periods) and that for the national level analysis was collected from the National Marine Fishery Data Centre (NMFDC) of the ICAR-CMFRI (1985 to 2017). Data for the size composition of the fishes were gathered by sampling through the personal visit to the fishing harbours fortnightly from January 2013 to December, 2016.

Collection of spatially referred catch data and Analysis

Using specially designed and pre-tested log sheet, the spatially explicit catch and effort data was collected from the fishermen for each voyage made during the period. The data was tested for accuracy by triangulation, queries and by plotting in the Google Earth software. Thus

data for 567 fishing operations spread across January, 2013 to December, 2016 covering all the fishing months were collected. Remotely sensed environmental parameters were collected from the MODIS Aqua images downloaded from the NASA-Ocean colour site (oceancolor.gsfc.nasa.gov). Analysis was carried out using MS Excel, GIS software (Geomedia Profesional 2014) and generalized additive model (GAM).

Results and Discussion:

Longtail tuna Fisheries in the northern Arabian Sea

Results of analyses of the nominal catches by the different countries in the northern AS indicated that Iran with an average landing of 40,0032 t was the major contributor followed by Pakistan (10,541 t), Oman (8304 t), India (7176 t) and Yemen (4186 t). These countries together constituted nearly 73% of the LOT landings in the Indian Ocean and nearly 99% of the landing in the northern AS during 2016. The results indicated that the continental shelf area of India is the highest (29.6 lakh sq. km) while the highest catch of LOT was in Iran (Fig.2.1). Pakistan and Yemen also had higher proportion of catch in comparison to the CS area in possession.

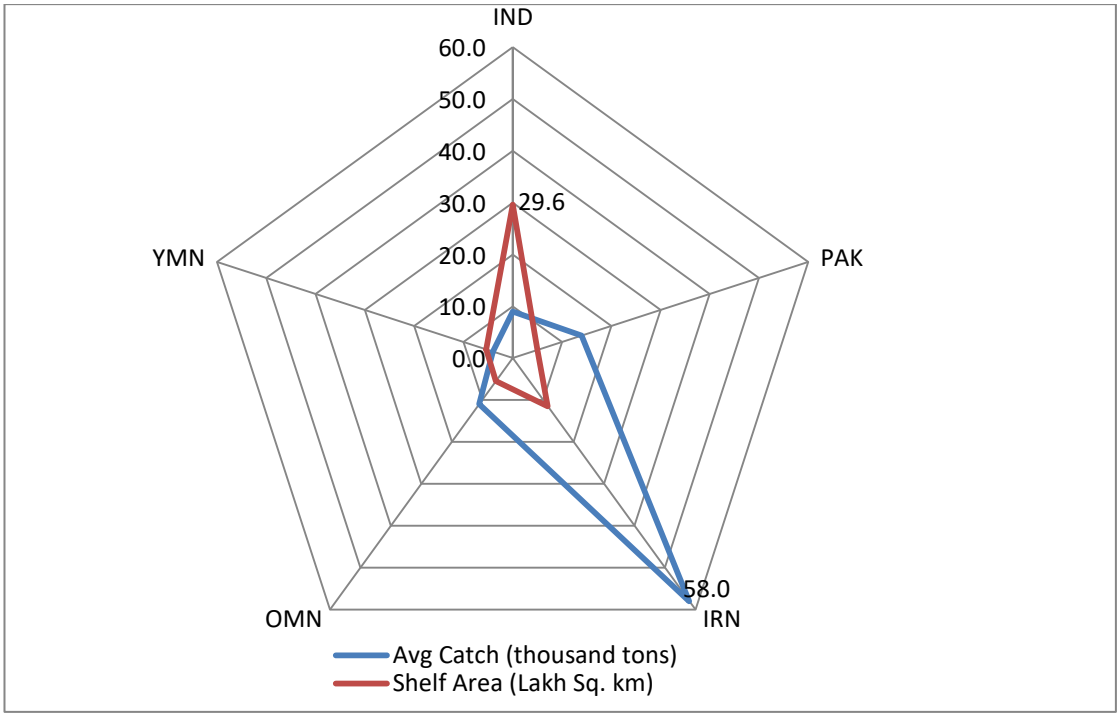

Figure 2.1: LOT landing by countries in the Northern Arabian Sea *vs* their Continental Shelf area (India (IND), Oman (OMN), Pakistan (PAK), Yemen (YEM) and Iran (IRN).

Yesaki (1994) considered extent of continental shelf area to be a limiting factor for global distribution of longtail tuna. The results of the present study however indicated that the area of CS alone does not decide the quantity of LOT landings by different countries. Better productivity of Persian Gulf, the Oman Sea and the northern Arabian Sea coupled with the differential fishing effort could be the reason for the variation in catch observed. Detailed information on fishing

effort expended in each region would more accurately reveal differential abundance of longtail tuna in the region.

Longtail Tuna Fisheries in India

Longtail tuna landing in India ranged from 109 t in 1986 to 13,926 t in 2012 and depicted a linear increasing trend during the period. Longtail tuna landing increased steeply since 1990s to reach a peak in 2000 followed by a fall in 2003 and 2009 (Fig. 2.2). Thereafter, the landing increased to reach the highest ever figure in 2012. In India, the west coast contributed 99.9% of the catch with Gujarat alone contributing 79% and Gujarat and Maharashtra together (northwest coast) constituting nearly 93% of catch. Hence the longtail tuna catch made along the North West coast dictated the landing trend of the species in India.

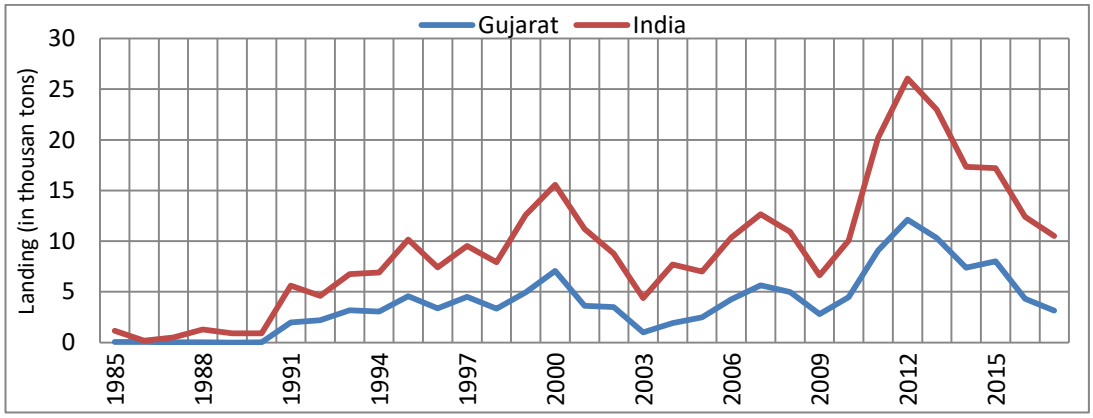

Figure 2.2: Trend of longtail tuna landing in India and Gujarat (Annual Landing (t) during 1985 to 2017)

Studies by Abdussamad *et al*. (2012a), Ghosh *et al*. (2010) have detailed the pattern of longtail tuna landing in India with the contributions by maritime states as well as by regions. The present results are in tandem with their reports.

Longtail Tuna Fisheries in Gujarat

Longtail tuna landings by gillnetters (pooled effort for outboard gillnetter and mechanised gillnetters) in Gujarat have registered a steady increase over the years despite fluctuations in some years, with the catch ranging from a mere 1 ton in 1989 to 12,136 t in 2012 (Fig.2.3). The catch rate analyzed for the past 10 years (2006-15) depicted an upward trend with inter-annual variations. Increase in fishing effort was evident consequent to an exceedingly good catch in 2011 leading to further increase in catch in 2012 but with a lower catch rate. The longtail tuna formed part of tuna catch in all months of the fishing season in Gujarat with the major peak in February and minor peak in October. Lowest landing was recorded during May.

The fishery was composed of fishes of the size range 258 mm (November, 2013) to 819 mm (September, 2014) with the mean size at 589 mm (Fig.2.4). Most (80%) of the fishes caught were in the size range of 50 to 70 cm. Maximum sizes in all the three seasons were almost

close to each other with the post monsoon having the highest size and the winter having the widest size range. Seasonal variations in the size were not significant (*p* value 0.951).

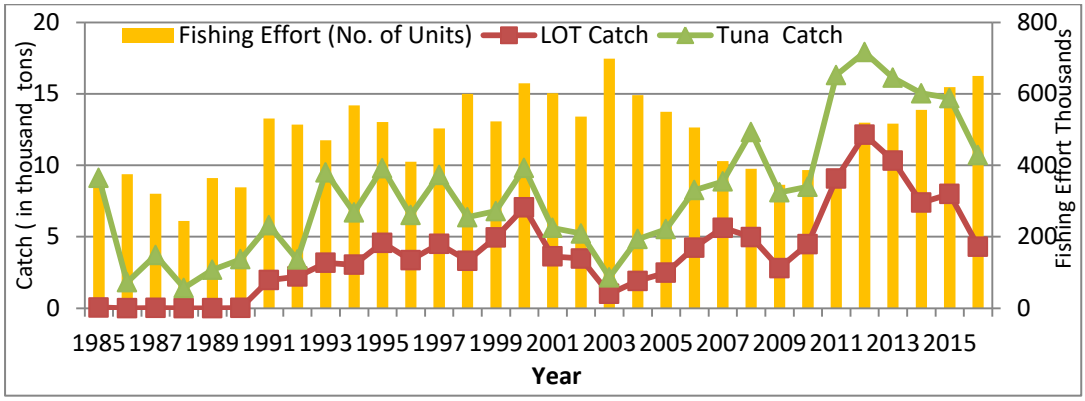

Figure 2.3: Trend of annual catch of LOT, neritic tunas and tunas against the fishing effort (Large-mesh Gillnet) (1985-2016)

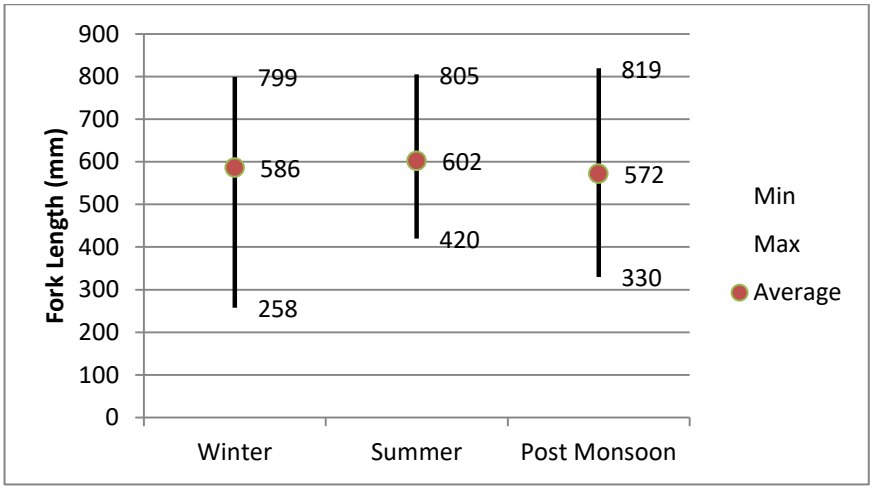

Figure 2.4: Seasonal variation in size composition of LOT fisheries of Gujarat (2013-16)

The steady increase in longtail tuna landing from 1990s through 2000s and the increased catch rate may be attributed to several reasons and includes improvements in fishing techniques like the introduction and widespread use of efficient nylon monofilament gillnets (Thomas, 2010); replacement of the small meshed (<85mm) demersal oriented gillnet fishing in shelf areas to a more resilient pelagic fishing using large meshed (>140mm) pelagic gillnets (Kasim and Khan, 1986; Polara *et al*., 2014) and continued expansion of the fishing areas to beyond 50m depth zone with the aid of larger (16m OAL) dedicated gillnetters (locally known as *Bethada*) fitted with engines of higher horsepower; navigation and communication aids (Polara *et al*., 2014).

Variation in distribution of different sized longtail tuna has been reported off the east and west coast of Australia (Serventy, 1956; Wilson, 1981) and Japan (Nakamura, 1969; Fukusho and Fujita, 1972). Yesaki (1982) reported size group differences in distribution with respect to inner and outer neritic regime along the Phuket Coast. Progressive increase in mean length of longtail tuna along the eastern Arabian Sea starting from the south-west coast of India (50cm)

through the north-west coast of India (61.9cm) to the Gulf of Oman (74cm) was reported by Kaymaran *et al*. (2011) and Abdussamad *et al*. (2012a) and the largest captured longtail tuna (142mm) was caught off Salalah, Oman (Dawood *et al.*, 2014).

Spatial and Seasonal difference in abundance of longtail tuna

The longtail tuna formed a part of gillnet catches with varying catch rates throughout the year. Bulk of the landing occurred during the post monsoon months (September to November) and winter months (December to February). Spatial expanse of fishing effort and the Catch per Unit Effort (CPUE) varied across the seasons. The highest CPUE (40 nos. per hour) was obtained at depth zone between 50 m and 200 m off Veraval. CPUE values were higher in the Saurashtra Coast as compared to other regions. Area of fishing and the catch rates varied across the seasons/depth zones (Fig. 2.5&2.6). Areas with higher CPUE was typically restricted to the central Saurashtra at depths starting from 20 m onwards in winter and highest CPUE values (35 nos. per hour) occurred off Porbander at depth zones around 50. Whereas in summer, fishing occurred typically beyond 30 m depth zone unlike other seasons and the highest CPUE values (20 nos. per hr.) were obtained at depths around 200 m and beyond.

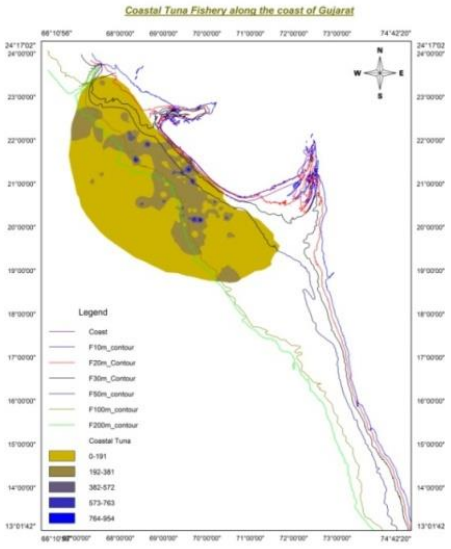

Figure 2.5: Map showing the areas of abundance of neritic tunas

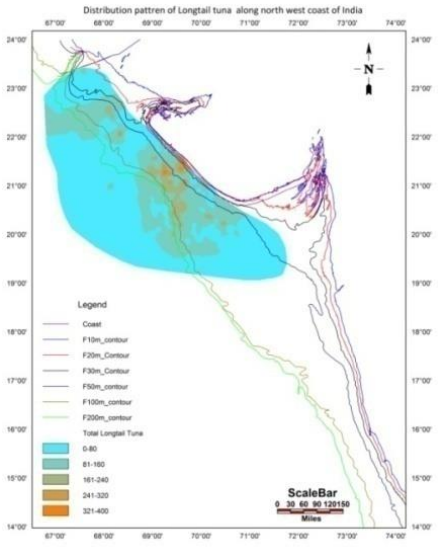

Figure 2.6: Map showing the abundance pattern of longtail tuna

The LOT catches were negligible or absent in mouths of the Gulf of Khambhat and the Gulf of Kachh, where a typical geomorphology and coastal processes exists and are known for their high energy tide driven systems causing the areas to be turbid (Kumar and Kumar, 2010; and Kunte *et al*., 2003). Increased Chlorophyll-*a* content, phyto and zooplankton diversity and biomass of seaweed along Veraval as compared to the Gulf (Reghunathan *et al*., 2003) indicate availability of relatively transparent water along the coast of Saurashtra. The absence of longtail

tuna in turbid waters of the Gulf and presence along the Saurashtra Coast testified the basic tenet that longtail tuna though typically a neritic species tend to avoid estuarine areas with high turbidity and low salinity (Collette and Nauen, 1983; Yesaki, 1993 and Griffiths, 2010a).

Habitat and influence of Environmental Parameters on the distribution of Longtail tuna

Typical movement pattern of the fish over the seasons across the depth zones necessitated to find out the environmental cues guiding the movement. The relationship between CPUE and the environmental variables is proven by the empirical cumulative distribution function (ECDF). The cumulative distribution curves of the two variables are different and the degrees of the differences between two curves (D (t)) are significant ($p < 0.01$). The SST ranged from 25 to 27.5°C and chlorophyll-*a* ranging from 0.02 to 2mg/m^3. Longtail tuna catch indicated an increasing trend from September to February where it peaked; and thereafter the CPUE sharply declined up to the end of fishing season (Fig. 2.7). As per the GAM model, suitable ranges of SST ($p<0.01$) was between 24.5 and 27.5°C whereas that of chlorophyll ($p<0.01$) was from 0.5 to 2mg/m^3. The result showed that combined effect of SST and chlorophyll concentration was the best for prediction of longtail tuna catch rate than individual parameters. The model predicted higher abundance of longtail tuna in regions where the SST ($p<0.01$) ranged from 24.5°C to 27.5°C and chlorophyll ($p<0.01$) from 0.5 to 2 mg/m$^{3.}$ The ambient SST range was similar to that suggested for longtail tuna fishery in other areas around the world (Mohri *et al*., 2009a; Mohri *et al*., 2009b; Kawatsu *et al*., 2011). It is well established that the SST is an important predictor of tuna catch (Sund *et al.,* 1981; Anand *et al.,* 2005 and Kunal *et al.,* 2014). Optimal foraging theory predicts that organisms seek out food items at locations where there is a higher probability of finding prey, hence reducing the energy utilized in searching for prey (Reese *et al.*, 2011).

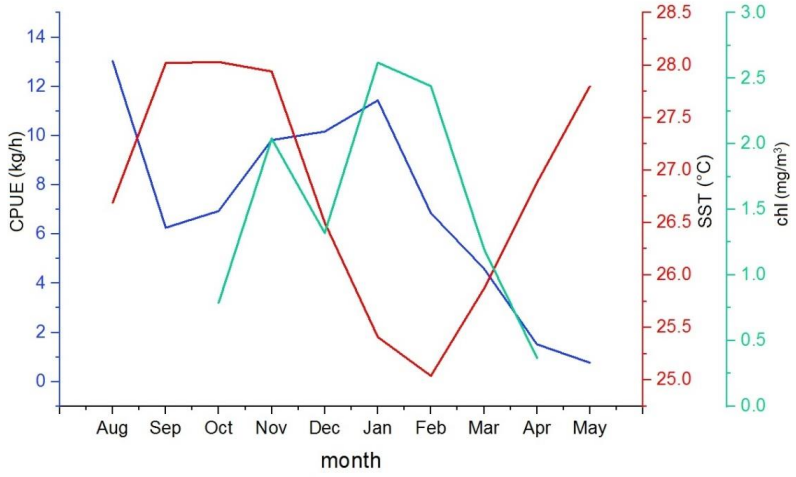

Figure 2.7: Plot shows monthly variation (2013-2015) in longtail tuna CPUE with respect to SST and chlorophyll off Gujarat Coast.

Both SST and chlorophyll influenced the CPUE of longtail tuna throughout the year with the CPUE following a similar trend of chlorophyll and an opposite trend of SST. The higher CPUE was observed from November to January when the SST declined and ranged from 27.94°C to 25.41°C and the chlorophyll from 1.32 to 2.62 mg/m^3 indicating that a lower SST and higher chlorophyll provided suitable environment for longtail tuna catches as a lower SST and higher chlorophyll indicate nutrient richness of the waters (Solanki *et al.*, 2001). Solanki *et al.* (2001), Mansor-Shastri *et al.* (2001) and Dwivedi *et al.* (2005) also found the prediction of fish aggregation to be better when the remotely sensed image of SST is overlaid on chlorophyll. Combination of the SST and chlorophyll can complement one another for determining potential area of marine pelagic resources (Montgomery *et al*., 1986). The SST was observed to be the dominant variable in the model for prediction of the catch.

Chapter 3: Reproductive biology, diet and feeding pattern of longtail tuna caught off Gujarat, India.

The chapter describes detailed reproductive and feeding biology of the species with the data collected during 2013-2016. Different indexes on the proportion of sexes, maturity, spawning, etc. with seasonal and ontogenetic variation have been worked out under reproductive biology section. Indexes related to prey preferences, feeding pattern and feeding intensity with seasonal and ontogenetic variations have been described under the feeding biology studies.

Materials and Methods:

Samples for the biological analysis were drawn periodically from the fishing harbours in Gujarat following random sampling protocols during 2013-2016. Samples were analysed in the fishery biology laboratory of CMFRI, Veraval Regional Centre. Important measurements of individual fish samples were recorded. The fishes were then dissected to remove the gonads and stomach for various biological analyses. Data needed for reproductive biology studies such as sex ratio, length at maturity, percentage of spawners and gonado-somatic index were recorded and analysed using standard procedures and protocols. The stomach and its contents were analysed to get the feeding intensity and diet composition.

Reproductive Biology of Longtail tuna

Distribution ratio of males to females

Sexes in *T. tonggol* were separate with no distinguishing external features. Analysis of the monthly sex ratio of males and females revealed that the overall sex ratio was 1:2.11 with a preponderance of females throughout the year except in May. *Chi* square test also indicated significant ($p < 0.5$) dominance of females in January, March, April, September, November and December. Similarly, females dominated in all the length groups except in 75-80 cm length

range. Percentage of males in different length classes exhibited a significant increasing trend with increase in fish length and that of females exhibited a significant decreasing trend (Fig. 3.1 and 3.2). Most studies on the species world over haven't observed any gross deviation in the male: female ratio of 1:1 (Klinmuang, 1978; Wilson, 1981; Griffiths *et al.,* 2010a). However, there isn't any information on the sex ratio of the species in the Arabian Sea region for a comparison of the results. Griffiths *et al.* (2010a) indicated a (2:1) bias towards males for fishes above 100cm along the east coast of Australia. Increasing trend of males in the larger size classes has been noticed for several *Thunnus* species (Sudarshan *et al.,* 1991 and John and Sudarshan, 1993; Wild *et al.,* 1995; Schaefer, 1998; Farley *et al*., 2003; Rohit and Rammohan, 2009).

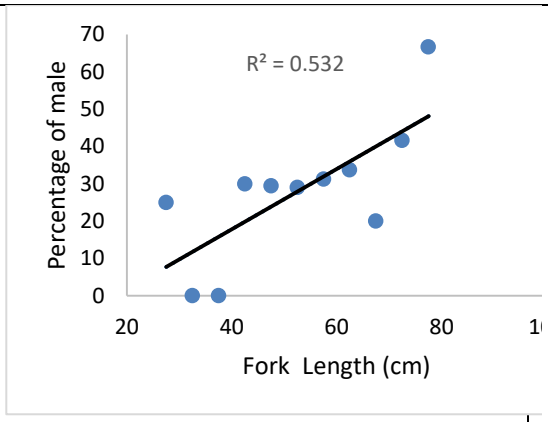

Figure 3.1 Percentage of male in different length classes of *T. tonggol* (2013-16)

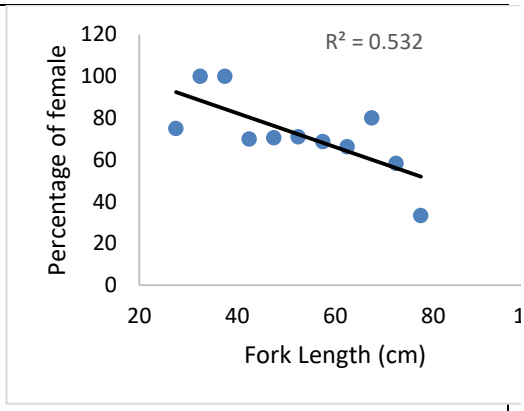

Figure 3:2 Percentage of female in different length classes of *T. tonggol* (2013-16)

Length at maturity

The logistic curve indicated fifty percent of *T. tonggol* in the population attained sexual maturity when their body measured a total length of 607 mm and the individuals of this size were observed in all months except May and June. There seems to be a large difference between the lengths at first maturity of females between the regions reported so far. *T. tonggol is* reported to attain sexual maturity at 39.6cm in the Persian Gulf and Oman Sea (Hedayatifard, 2007) and 37 cm in Taiwan waters (Chiang *et al.,* 2011). Yesaki (1982) and Cheunpan (1984) based on their studies from Thailand waters have reported the length at maturity to be 43 cm and 40 cm (FL) respectively whereas in the waters of Australia and Papua New Guinea, macroscopic inspection of gonads by Wilson (1981) revealed that longtail tuna first matured when it attained a TL or FL of 51 cm and 60 cm in the respective region. Previous studies in the Indian waters revealed that the longtail tuna attained first maturity when it reached a FL of 51.1cm (Pillai and Ganga, 1985) and 50 cm FL (Abdussamad *et al.,* 2012a); however, these values are lower compared to the length at maturity arrived at in the present study.

Maturity and spawning

Females with immature ova (stages I and II) were observed throughout the year, while those with mature ova (stages III, IV) were observed in all months except in May and June. Females with spent gonad condition (stage V) were observed only in February, March and April. One-way ANOVA test revealed that there are significant differences in maturity stages of LOT over different months ((p-value 0.00). Abdussamad *et al.* (2012a), Yesaki (1982), Cheunpan (1984), and Hedayatifard (2007) are few other studies made across the globe that investigated their timing of spawning and opined that the peak season of spawning differed with geographical area and the exact factor is yet to be found.

Gonadosomatic Index (GSI)

Monthly GSI values varied significantly (p –value 0.00) (Table: 3.1), with an increase from December onwards reaching the peak in April. Thereafter, the GSI values dropped rapidly and lowest value was during May. This suggests that the ovaries were maturing continuously from December till April. Smaller peaks of GSI values were observed during August and November also. Most of the previous studies reported that the spawning occurs over a period of several months during the warmest period of the year in a particular region (Wilson, 1981; Griffiths *et al.,* 2007; Abdussamad *et al.,* 2012a). The present study is in tandem with these previous studies stating that the longtail tuna had protracted reproductive period.

Table 3.1: Results of One-way ANOVA: GSI versus Month (S = 0.2672 R-Sq = 35.16% R-Sq (adj) = 22.86%)

Source	DF	SS	MS	F	P
Month	11	2.2454	0.2041	2.86	0.005
Error	58	4.1407	0.0714		
Total	69	6.3861			

Food and Feeding

Prey Preference and Diversity

The diet comprised of 22 diverse groups/taxa comprising mainly of fishes (52%), crustaceans (26%) and cephalopods (4%) along with partially digested food items (10%) (Fig.3.3). A considerable quantity (8%) of plastic materials (8%) was also observed in the gut content. Fishes such as *Stolephorus* spp., *Rastrelliger kanagurta*, *Platycephalus* sp., *Trichiurus lepturus*, *Sardinella* sp., *Auxis thazard, Megalaspis cordyla,* Sciaenids and Clupeiods; crustaceans like *Solenocera* sp., *Squilla* sp., deep sea shrimps; and molluscs like the squid, cuttlefish and octopus formed the diet. Earlier studies (Yesaki, 1987; Wilson, 1981a and 1981b; Griffiths *et al.,* 2007; Abdussamad *et al.,* 2012a) categorised the species to be an opportunistic coastal epipelagic predator that mainly fed on small pelagic shoaling fishes, crustaceans and cephalopods.

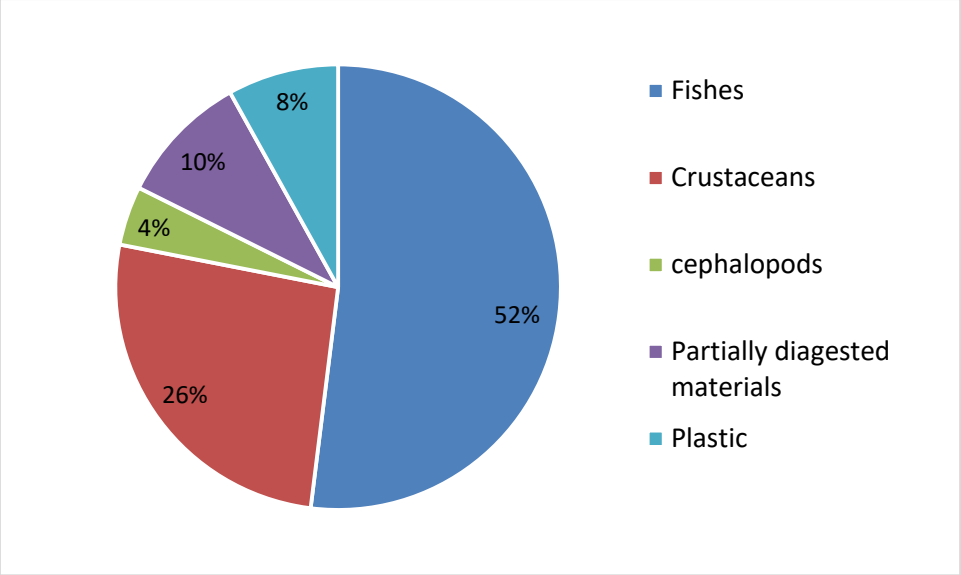

Figure 3.3: Major prey group constituting the diet of *T. tonggol* (2013-16)

Feeding intensity

Most of the examined specimens were with empty stomachs. The least proportion of empty stomachs (33.33%), was observed in fishes measuring 75-80 cm Fork Length (FL) group. The mean Stomach Fullness Index (SFI) were higher for females in all the length groups, except in 41-50 cm range (Fig. 3.4) whereas, results of *t* test analysis showed that SFI values between sexes for each size category of fish were not significantly different ($p > 0.5$). The stomach fullness index varied considerably among months (Fig. 3.5) and the values were lower during May (1.04 ± 0.19) and October (1.04 ± 0.17) and higher during March (2.88 ± 1.59) and August (2.02 ± 1.59). The pattern in SFI showed a direct relationship with the reproductive activity with stomach fullness being highest in the months of highest reproductive activity and vice versa (Fig. 3.6). The relationship between GSI and stomach fullness index was observed to be positive and statistically significant ($R^2 = 0.39$ and $P = 0.041042$) (Fig. 3.7). This could be explained by the fact that the fish requires more energy during spawning than during other phases. Some studies have pointed out that the reproductive activity is the period of highest nutritional demand for fishes (Martins *et al.,* 2005; Chiou *et al.,* 2006). The positive relationship of SFI with GSI in the remaining months could be due to increased presence of immature or maturing fishes in the catch as longtail tuna breeds throughout the year with one major peak and two minor peaks (Yesaki, 1982; Cheunpan, 1984; Griffiths *et al.,* 2007; Abdussamad *et al.,* 2012a).

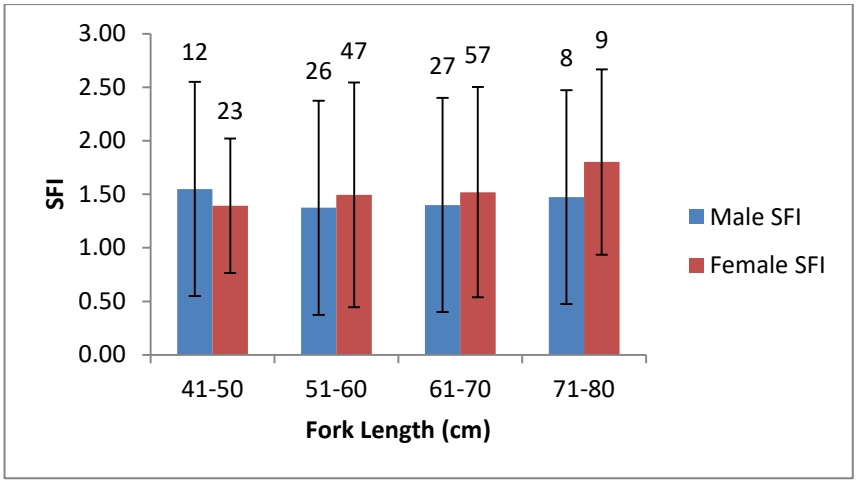

Figure 3.4: Stomach fullness index for different size classes of *T. tonggol* (vertical bars indicate ± standard deviation. Number of specimens examined is given above each bar)

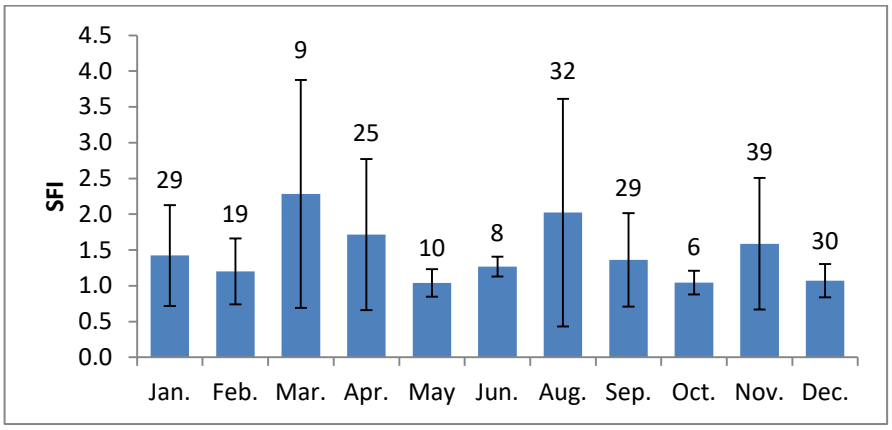

Figure 3.5: Monthly variation of stomach fullness index of *T. tonggol* (vertical bars indicate ± standard deviation. Number of specimens examined is given above each bar)

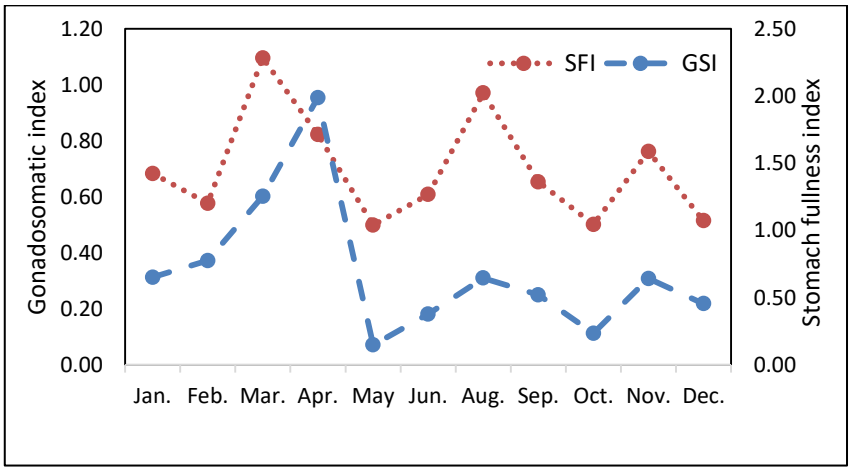

Figure 3.6: Monthly mean stomach fullness index (SFI) and gonadosomatic index (GSI) showing the relationship between feeding intensity and reproductive activity of *T. tonggol*.

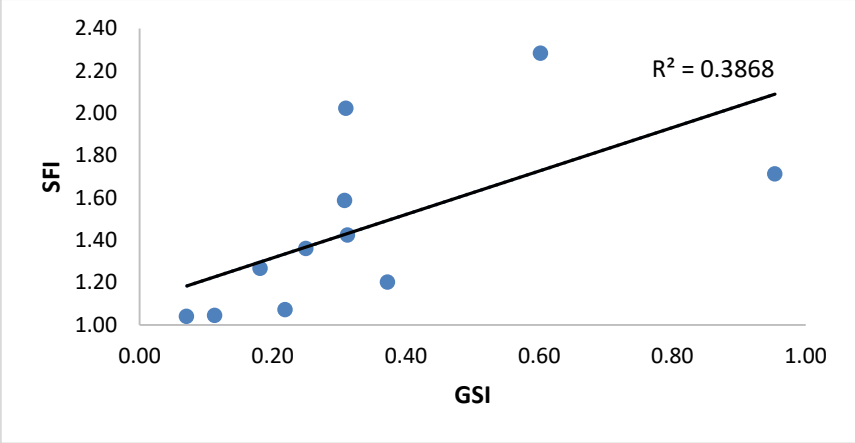

Figure 3.7: Plot showing the relationship between reproductive activities (GSI) and feeding intensity (stomach fullness index) for *T. tonggol*.

Chapter 4: Non-target species interactions in gillnet tuna fisheries, influence of depth and time of fishing on the interaction; and implications of it in fisheries management.

The chapter deals with the catch composition and its variations over the seasons in the multi-day gillnet fisheries of Gujarat observed during the period 2013-2016 with active and voluntary participation of fishermen. Interactions of non-tuna fishes including endangered, threatened and protected (ETP) species with the tuna fisheries; and the influences of seasons and depth of fishing area on the interaction are detailed. An approach integrated with the proactive involvement of the fishermen for gathering the spatio-temporal data of fisheries is discussed.

Materials and Methods

The spatially referred catch data collected during 2013-16 as explained in Chapter one was used for detailed analysis. Data comprises of species or group-wise catch (in numbers) in every fishing operation carried out in a spatially referred point. Analysis of the data for catch composition was done using MS Excel and one way ANOVA; and mapping was done using GeoMedia Professional 2014. Data for months were pooled and classified into post-monsoon (September-November), winter (December-February) and summer (March-May) and compared for seasonal variations. Tukey *post hoc* analysis was done to understand the inter-seasonal variations in the catch rates of different species. Nature and strength of interrelationship between major catch and the by-catch fishery resources as well as their level of dependency on each other were studied by correlation analysis using Pearson's correlation. The Principle component analysis (PCA) was used to reduce the complexity of data sets without losing information (Ragno *et al.,* 2007) and finds groups and sets of variables with similar properties. For the statistical analysis and plotting of data, R-Version R.3.5.0 and R studio 0.99.473 (http: //www.R-project.org.) was used.

Results and Discussion:

Results revealed that the fishing points were spread all across the continental shelf areas along Gujarat and to the adjacent oceanic region between 18°N and 23°N latitudes at depths ranging from 14 m to over 3000 m (Fig. 4.1). Majority of the effort was expended on the shelves off the Saurashtra coast between 20°N and 22°N latitudes at 50-100 m depth zone and only 17% was made in the oceanic areas *i.e.*, beyond the continental shelf break after around 200 m depth contour. Fishing in the oceanic areas was mainly during late winter (February) and summer months (March-May).

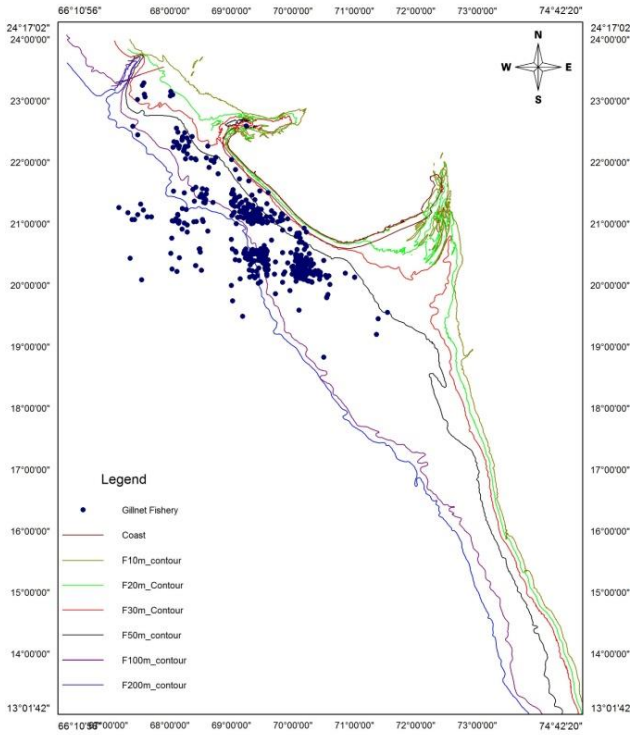

Figure 4.1 Spread of fishing points of the observed gillnetters (2013-16) (Blue dots indicate fishing point)

Catch Composition and its variations over the year

The gillnet catch covered 16 taxa comprising of commercially important species, low value bycatch (LVB) and ETPs consisted of turtles and dolphins. The tunas constituted 64.62% of the gillnet catch followed by non-tuna fishes (35.26%). The ETP species constituted only 0.12% of the total catch. Neritic tuna formed nearly 92% of the total tuna catch. The oceanic tunas (yellowfin and skipjack) formed 8% with their catch limiting to the winter and summer months. Unicorn leatherjacket constituted major catch in gillnets during winter months. There was exclusivity in abundance of unicorn leatherjackets visible from the analysis of composition of ten fishing operations wherein the species constituted the major catch. Analysis during different seasons indicated that majority of LVB were landed during winter months followed by post-monsoon. Minimal LVB landing during summer months indicated coastal nature of the LVBs. Catch rate of dolphins and turtles were 0.05 and 0.11 respectively. Turtles occurred in all

depth zones with the abundance being more between 30 m and 100 m depth contours while dolphins occurred at deeper waters close to 100 m and beyond 200 m depth contours (Fig.4.2).

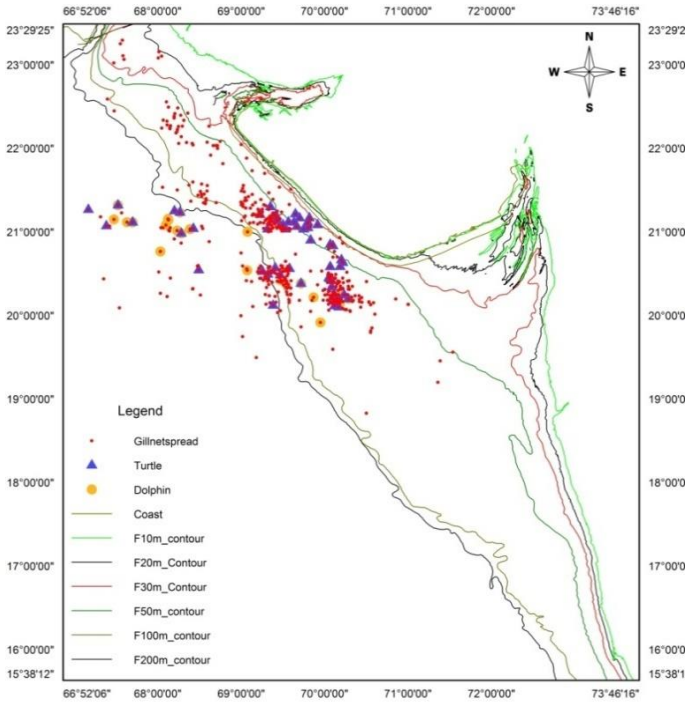

Figure 4.2. Spatial points of incidence of ETP species in gillnet fishing off Gujarat (2013-16) Red dots indicate fishing point, blue triangle indicate turtle, orange circle indicate dolphin incidence points.

Dominance of neritic tunas, especially the longtail tuna in the gillnet fisheries along the north-west coast of India have been established by many authors (Abdussamad *et al*., 2012a, b and Ghosh *et al.*, 2010). Moazzam *et al*., (2012) also reported a similar (60% tunas and 40% other resources) composition of catch in the gillnet fishery off Pakistan waters. The study confirms abundance of the neritic tunas in the neritic realms with an indication of its movement to oceanic areas during summer months. Migration of the neritic tunas, especially the adults to offshore areas have been reported for Kawakawa (*Euthynnus affinis*) in Taiwan waters (Chiou and Lee, 2004) and longtail tuna (*Thunnus tonggol*) in Thailand water (Yesaki, 1982). There was notably low incidence of sharks (1.5% of non-tuna catches) in the gillnet catch in the area of study contrary to the findings of Moazzam *et al*. (2012) from Pakistan waters (23% of the bycatch) and Shahifar (2012) from Iranian gillnet fisheries (18% of the bycatch).

Relationship of tuna catches with non-tuna and ETP species

Correlation studies of the catch rates revealed that the oceanic tuna catches had a positive relationship with neritic tuna and non-tuna species and negative correlation with leatherjackets and ETPs (Fig.4.3). The correlation was significant only with the neritic tuna species (p 0.01). Neritic tuna was positively correlated with the non-tuna species and negatively correlated with leatherjackets and ETPs. However, the correlations were not significant ($p > 0.05$). The catch of leatherjackets exhibited a significant positive correlation with non-tuna

species (*p* 0.000). The non-tuna catch had positive correlations with oceanic tuna, neritic tuna and leatherjackets and negative correlations with the ETPs.

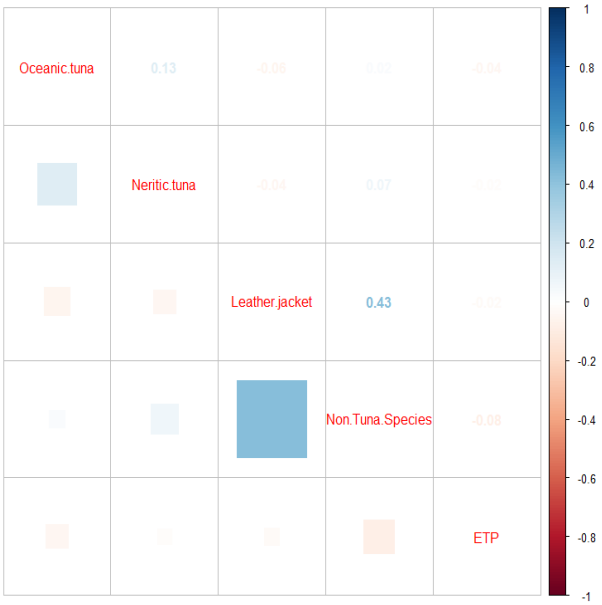

Figure 4.3 Correlation analyses of different groups in gillnet. Colour coding is provided alongside. (The colour intensity and size of the box represents the strength of the correlation)

Principal Component Analysis

The first three principal components in the PCA analysis together explained 72% of the total variations with 28.8%, 23.1% and 19.6% of variance respectively. PC1 accounted for 28.8% of the total variance with high positive loading for oceanic tunas and ETP species; higher negative loadings for leatherjackets and other non-tuna species and lower negative loadings for neritic tuna species. The oceanic and neritic tuna species showed negative loading in the case of PC 2 with 23.1% of the total variance (Fig.4.4).

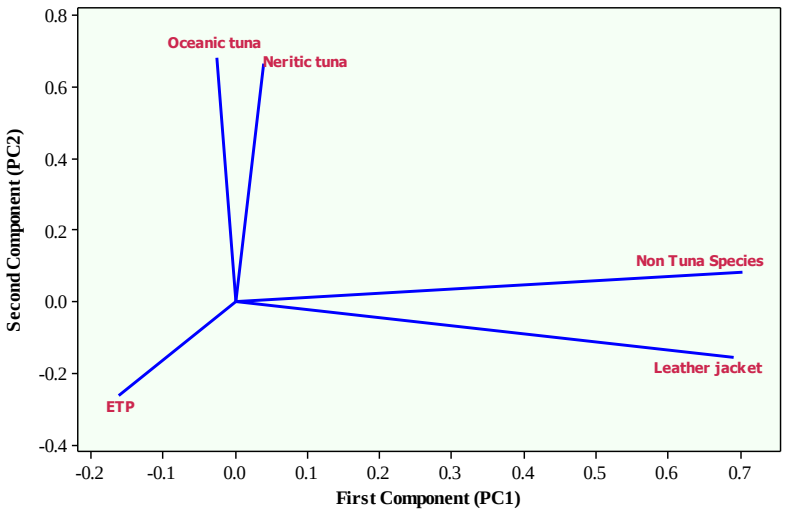

Figure 4.4. Results of the PCA Analysis of the large meshed gillnet fishery

Variations in catch rates of different groups across seasons and depth zones

The catch quantity and composition varied considerably over the seasons with the catch being higher during post monsoon and winter months. Catch and catch rate of different categories of non-tuna species also varied at different depth zones across the seasons. Analyses were done for neritic tuna, oceanic tuna, unicorn leatherjacket, other non-tuna species and ETPs. Results of the cases of Unicorn leatherjacket, other non-tuna species and ETPs are provided below.

Unicorn Leatherjackets:

The leatherjacket catches depicted a very clear statistically significant seasonal pattern (*p* 0.01) with the winter season ranked the highest indicating the catch rate is much high during these months followed by post monsoon season. The catches of leatherjackets in gillnets were not influenced significantly (*p* 0.10) by the depth of the fishing area. However, this fish did not occur at depths below 30 m and rarely occurred at depths below 50 m and above 300 m. Incidence of leatherjackets at deeper areas (>100 m) is seen more during the winter months. The GIS map indicated that the shelf area south of Saurashtra Coast between 50 and 100 m depth contour was the most productive ground for the leatherjackets with another minor congregation off Porbandar (Fig. 4.5).

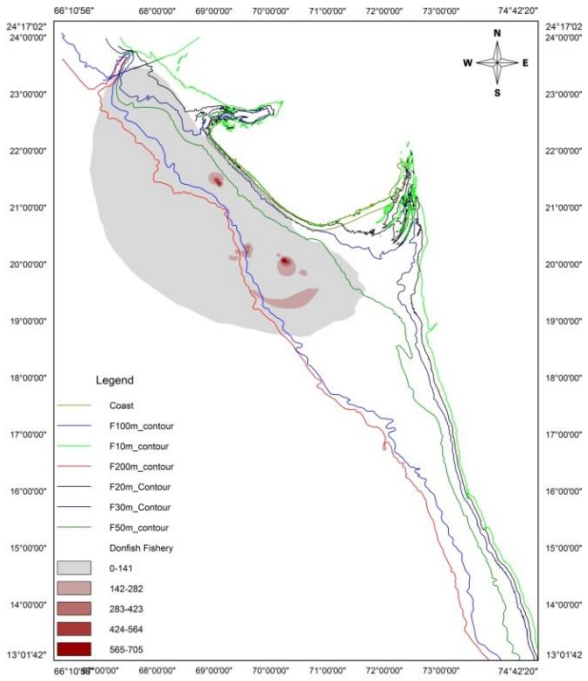

Figure 4.5. Areas of abundance of unicorn leatherjacket (*Aluterus monoceros*) off Gujarat Coast

Other non-tuna species:

Incidence of non-tuna species in the large-mesh gillnet fishery had clear seasonal pattern (*P* 0.000) with the catch rate being highest during post monsoon followed by winter and the summer, remaining distinctly lower than the average. Occurrence of non-tuna species in gillnets was significantly (p 0.01) influenced by the depth. The dot plot indicated higher catch rates of

non-tuna species occurring during winter months and its increased incidence in oceanic areas (>300m) (Fig.4.6).

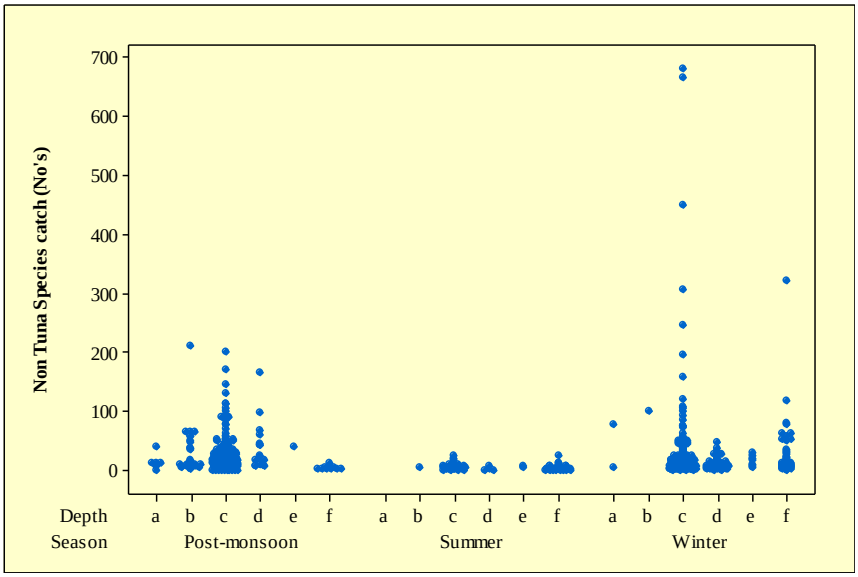

Figure 4.6 Dot plot of non-tuna species catches in gillnet across the seasons and depths

Endangered, Threatened and Protected Species

Incidence of ETP species in the gillnet operations varied from 0 to 3 numbers per operation. There was significant ($p < 0.05$) variations in incidence of ETPs in gillnet operations between seasons, with higher values and rate of incidence during summer months being much above the average. Turtle incidence was more in post-monsoon months while the dolphins occurred more during summer months. Depth had significant ($p < 0.05$) influence on the occurrence of ETP species in gillnet. Dot plot indicated higher number of ETPs (three numbers) in operations during winter and summer months, especially at oceanic areas (>200m).

Number of turtle entanglement reported (10%) in the study is much lower compared to the reports from neighboring Pakistan, where 1-2 green turtles and 3-8 olive ridleys were reported to be encountered in every fishing trip (Moazzam and Nawaz, 2014). Gillnet fishing fleet of Pakistan is larger (10-30m OAL) as compared to the Indian fleet and they undertake voyage up to 90 days and fish in grounds as far as 400 miles from the base station (Moazzam, 2012). On the other hand, the gillnet fishing fleet of Gujarat comprises of boats of maximum size up to 16m LOA (Polara *et al.,* 2014) and operate mainly on the shelves extended up to nearly 300 nm with a voyage duration lasting for 7 days. Low incidence of turtles in gillnets of Gujarat can therefore be attributed to the smaller scale of fishing.

The study demonstrates potential role of fishermen in resources management, paving way for their proactive involvement in resource management and conservation. Awareness need to be generated among the fishermen in not only conservation of ecologically important resources and compliance of prescribed management measures but also in willingly participating in vessel based data generation enabling regular monitoring of the catches and bycatch.

Chapter 5: Stock structure of longtail tuna in the northern Indian Ocean region and the status of the stock off Gujarat, north-west coast of India.

The chapter deals with the stock structure of the species in the wider Indian Ocean region with samples from geographically well separated regions *viz*. Gujarat, Kerala and Andaman & Nicobar Islands using genetic tools. Besides arriving at the intermediate stock parameters, the stock status of the species has been estimated using analytical model (Thompson & Bell, 1934) and holistic models (Schaefer Model and CMSY).

Materials and Methods:

Stock structure study was carried out using genetic tools. Tissue samples were drawn from the fish samples collected at Veraval (Gujarat), Kochi (Kerala) and Port Blair (Andaman and Nicobar Islands). Standard protocols were followed for the extraction, amplification, purification and sequencing of the genetic materials. A 758bp of the control region and a 576bp region of COI of *T. tonggol* was amplified in all the sampled individuals for phylogenetic and population genetic characteristics. Population genetic structure was analysed using the F-statistics, ΦST (Excoffier *et al.,* 1992) using 20,000 permutations to estimate significance (calculated with Arlequin Version 3.5.1.2, Schneider *et al.,* 2000). Analysis of molecular variance (AMOVA) was carried out to estimate the differences between stocks in Arlequin Version 3.5.1.2. The sequence divergence values were estimated using the algorithm of Kimura 2P (Kimura, 1980) for COI gene sequences and Tamura and Nei (1993) for control region sequences. Sequential Bonferroni correction was carried out and P values adjusted accordingly for all the tests (Rice, 1989). Haplotype network diagram was constructed using Network 4.6.1.3 (available from fluxus- engineering.com) for both control region and COI haplotypes using parsimony method.

Samples for the biological studies including length frequency data were collected following multistage random sampling techniques suggested by Srinath *et al.,* 2005. Length and weight data thus collected during 2013-2016 were used for the analysis. The length-weight relationship of the species was calculated as described in Le Cren (1951). The ELEFAN I (Electronic Length Frequency Analysis) module of FiSAT software (Gayanilo *et al.,* 1996) was used for estimation of Von Bertalanffy growth parameters (Asymptotic length ($L\infty$) and growth co-efficient (K). Size at first capture (Lc 50) was estimated following Pauly's method (Pauly, 1984) and age at zero length (t_0) calculated using Pauly's empirical equation (Pauly, 1979). Natural mortality (M) was calculated following Pauly's empirical formula (Pauly, 1980), The FiSAT software (Pauly 1983) was used for calculation of total mortality (Z) from length converted catch curve, whereas fishing mortality (F) was estimated by Pauly's method (Pauly, 1980). Fishing mortalities per length class was obtained using the length structured Virtual Population Analysis (VPA) of FiSAT. The biological reference points (BRPs) of LOT fisheries off Gujarat were estimated following three methodologies viz., the Analytical Model (Thompson and Bell,

1934), biomass based models model (Schaefer, 1954) and the CMSY models (Froese *et al.* (2016).

Results and Discussion

Stock structure

The best evolutionary model for nucleotide substitution for the control region data was the Tamura 3-parameter (T92) (Tamura, 1992) with invariable sites (I=0.60) and rate heterogeneity (G=0.61) (T92+G+I) and for COI gene region nucleotide substitution was Kimura 2p. The phylogenetic tree constructed using both sets of sequences supported the existence of two well separated clades or haplogroups with significant bootstrap values without any geographic pattern. Similar pattern of two well separated clades was observed in haplotype network diagram constructed using both sets of sequences. Genetic differentiation among longtail tuna populations from different locations was tested using ΦST pair-wise comparisons of both control region sequences and COI gene sequences. The overall levels of genetic differentiation were not significant (p> 0.001) in all the analyses with a global ΦST value of 0.0.017 with control region sequences and 0.068 with COI gene sequences (Fig.5.1).

The results ruled out existence of any stock structure of *T. tonggol* in the wider northern Indian Ocean region along the Indian peninsula as well as the archipelagic waters of Andaman & Nicobar Islands though two halogroups *sans* any geographic pattern were observed in the eastern AS along the west coast of India. The outcome is supported by results of Phylogenetic tree and AMOVA. Similar observations were also made by Kunal e*t al.* (2014), based on their study covering two sampling points along the northwest coast of India asserting the existence of single panmictic population of LOT in the north western shelf of India. Analysis of COI sequences while confirming the homogeneity of the stock in the Indian Ocean signaled connectivity of these stock with that of the West Central Pacific. However, coastal pelagic fishes generally have more geographic population subdivisions than oceanic species (Crosetti *et al.,* 1994; Rossi *et al*., 1998) probably because of their inshore habitat requirements, shorter migration distances, and vulnerability to climatic fluctuations. Lack of population structure for LOT may be due to the fact that LOT is a slow growing and long lived species (Yesaki, 1993 and Griffith *et al.,* 2010) compared to all the other neritic species.

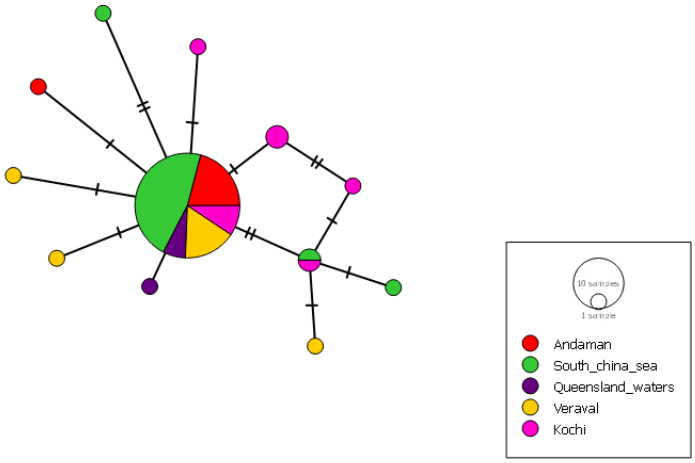

Figure 5.1: Median joining network diagram constructed using COI sequences

Stock Status

Length - weight relationship:

The size of the fish landed and sampled ranged between 30 to 80 cm in fork length and 341 to 6670g in wet weight. The study revealed that the pooled slope 'b' of the regression equation was isometric with value of 2.44 ($p<0.05$) indicating an isometric growth pattern of the species (Table 5.1). The Length-Weight relationship in the present study is therefore expressed as W=0.1229XL2.4448; W in grams and L in centimeters. Earlier reports on the length weight relationship and 'b' values of LOTs from the region include those by James *et al. (*1993), Khorshidian and Carrara, (1993), Darvishi *et al. (*2003), Kaymaram *et al. (* 2013), Abdussamad *et al*. (2012a) and Vinod *et al*. (2017).

Table 5.1 Values of Length-weight relationship of Longtail tuna

	a	**b**	**r^2**
Males	0.1345	2.4222	0.9339
Females	0.1162	2.4590	0.8879
Pooled	0.1229	2.4448	0.9046

Growth parameters

The growth parameters, estimated using ELEFAN I programme were asymptotic length (L_∞)-104.0 cm and growth coefficient (K) - 0.27 year−1. The t_0 value was estimated at 0.073 years and the Von bertalanffy growth equation expressed as: Lt = 104 [1 – e -0.27(t -0.073)]. The highest L_∞ value reported for the Indian waters was 123 cm by Abdussamad *et al.* (2012b) for pooled data from different parts of the country wherein the size ranged from 23 cm to 111cm. The K value depends on the range of the length data in the series, which in turn depends on the sample coverage and the sampling technique. Higher values of K are noted in Thailand and Japanese waters where the fishery is predominantly by the purse seiners targeting smaller sized fishes (Grifiith *et al.*, 2010).

Length at first capture (Lc 50)

The major gear operated along Gujarat Coast to exploit longtail tuna is the gill net followed by trawl nets; hence mesh size of gill net as well as cod end of trawl net determines the Lc 50 of *T. tonggol*. The length at first capture estimated in the present study (62.10 cm) is higher than that estimated by Abdussamad *et al*. (2012b) for the northwest coast (51.9 cm). Increase in mesh size of gillnets and expansion in the fishing areas to deeper waters could be attributed as the reasons for this enhancement in the size at capture.

Mortality rates, Exploitation ratio (E) and Virtual Population Analysis (VPA)

The natural mortality (M), fishing mortality (F) and total mortality (Z) obtained for LOT in the present study were 0.56 year−1, 1.21 year−1 and 1.77 year−1, respectively. As per the relative yield per curve, the exploitation ratio (E) was 0.68, while maximum exploitation ratio (L_{max}) was 1.00. The values of L_c/L_∞ and M/K taken for estimation of Y'/R were 0.739 and 2.07 respectively. The species became more vulnerable to the gear when it attained a fork length of 52 cm and thereafter the fishing mortality increased progressively. The maximum fishing mortality of 1.21 $year^{-1}$ was recorded when the fish attained a FL of 80 cm.

There are several studies on the mortality parameters of the species from the region as well as globally. Reports of M values of 0.49 and 0.44 by Khorshidian and Carrara (1993) and Kaymaram *et al*. (2013) for LOT collected from the Persian Gulf and the Oman Sea respectively are comparable to the present results. The earlier estimates of F ranged from 0.167 (Griffith *et al.*, 2010) from Australia to 4.83 (Pillai and Ganga, 1985) from Veraval in India. The Total mortality (Z) value reported in the present study is much less (1.77 year-1) compared to earlier studies viz., 3.84 (Supongpan and Saikliang, 1987), 6.14 (Pillai and Ganga, 1985) and 5.20 (Pillai and Ganga, 1985). The statement by Beverton and Holt (1956) that the natural mortality coefficient of a fish is directly related to the growth coefficient (K) and inversely related to the asymptotic length (L_∞,) and the life span is found true in the present results. The exploitation ratio (E) of *T. tonggol* reported in the present study (0.68) is lower than the previous estimates (0.799 by Abdussamad *et al*. (2012b), 0.7 by Pillai and Ganga (1985). The M/K ratio (0.739) in the present study was also within the normal range of 1–2.5, as suggested by Beverton and Holt (1959).

Biological Reference Points

The MSY and F_{MSY} values estimated by the biomass based methods (CMSY, BSM and Schaefer) were in the vicinity while that predicted by analytical model remained much different. B_{MSY} estimated by different methods varied from 9487 t (Thompson & Bell) to 14484 t (Schaefer Model). All the models predicted the F_{2016} to be lower than the F_{MSY}. The B_{2016} was predicted to be lesser than the B_{MSY} by all the models except the Thompson & Bell model (Fig. 5.2), which predicted the B_{2016} to be much higher than the B_{MSY}. The mean of MSY values by three biomass models was 7481 t and that by all the four models was 7271 t. The catch of 2016 and the mean

catch during preceding three years (2014-16) (6563 t) is lower than the MSY values postulated by all the models as well as the mean of all the four model values. A look at the current state of the *T. tonggol* stock as per the four methods revealed that the stock is overfished but not subject to overfishing as per the biomass based models, while the analytical model (Thompson & Bell) assessed the fishery to be neither overfished nor subject to overfishing. The fishing mortality is lower than the F_{MSY} in all the estimates. Though the biomass based models estimated the stock status to be bleak with the current biomass being lower than the biomass needed to ensure maximum sustainable yield, the fishery showed signs of improvement by way of reduction of fishing pressure in the later years (Fig.5.3). Further, the trajectory of the uncertainty in the BSM analysis is inclined towards higher biomass. The analytical model, however, estimated the biomass and the spawning biomass to be much higher than the biomass and spawning biomass needed to ensure the sustainable yield.

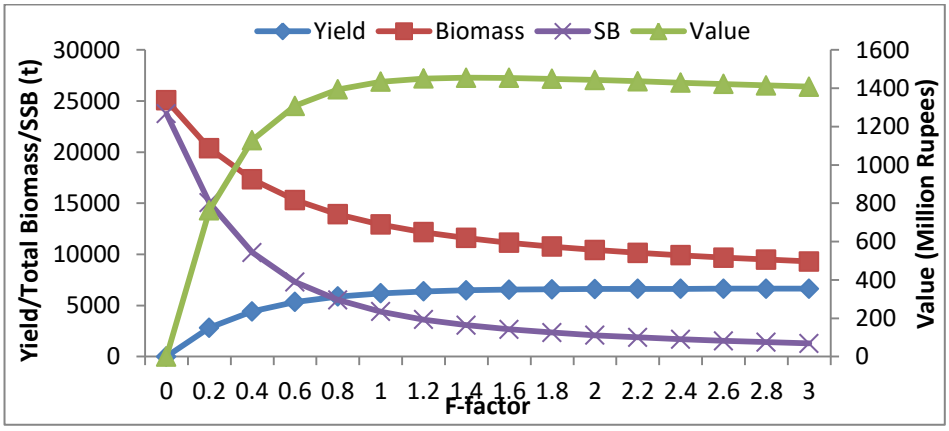

Figure 5.2 Results of the Thomson and Bell analysis of *T tonggol*

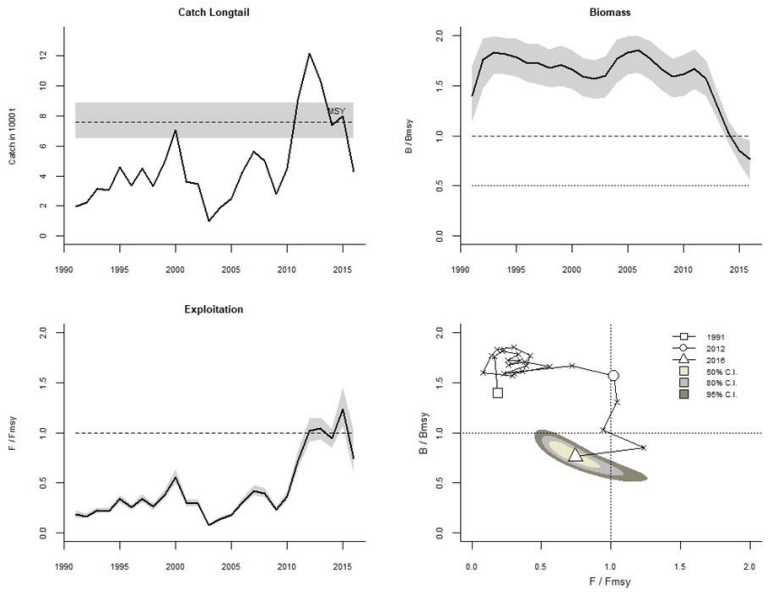

Figure 5.3 Graphical output of the CMSY for management purpose (based on BSM analysis)

It is advisable to use both analytical and biomass dynamic approaches wherever data is available to have a comparison of the results (Hoggarth *et al*., 2005) and hence, estimation of stock using two biomass dynamic model (Schaefer and CMSY) was also made. The latest assessment of the stock of LOT in the Indian Ocean region is that by the IOTC (IOTC–2017a) using Catch-MSY, Optimised Catch Only Methods (OCOM) and Stock Reduction Analysis (SRA) methods. The assessments by all the methods suggested that the stock is subject to overfishing while the CMSY and OCOM suggesting it to be overfished as well.

Introduction of fleet of larger multiday gillnetters since 2008 (Polara *et al.,* 2014) and expansion of the fleet and the area of operation in the subsequent years have led to this spurt in landing of LOT in Gujarat. Exploitation of the resources much above the MSY levels in 2012 and 2013 could have reduced the biomass to very low level affecting the recruitment leading the catch to stoop in 2016. However, it showed signs of relief with the catches of LOT in 2017 showing an increase over 2016.

Chapter 6: Summary and Conclusion

The present study aimed to review, update and generate information on the fishery, distribution, habitat, biology, stock structure and stock status of longtail tuna in the region; with special reference to the northern Arabian Sea off Gujarat, northwest coast of India.

- The study revealed the present state of the longtail tuna fishery in the northern Arabian Sea region and along the coasts of India with emphasis on Gujarat Coast. Though India has the largest extent of continental shelf, it is only at 4th position in longtail tuna landing. Better productivity of Persian Gulf, the Oman Sea and the northern Arabian Sea coupled with the differential fishing effort could be the major reason for the variation in catch observed. Detailed information on fishing effort expended in each region would more accurately reveal differential abundance of longtail tuna in the region.
- The northwest coast comprising of Gujarat and Maharashtra accounted for nearly 93% of the longtail tuna landing in west coast of India and nearly 83% of the all India catches. Improvements in fishing techniques like the introduction and widespread use of efficient nylon monofilament nets, replacement of the small meshed (<85mm) demersal oriented gillnet fishing in shelf areas to a more resilient pelagic fishing by adopting larger meshed (>140 mm) pelagic gillnet and continued expansion of the fishing areas to beyond 50 m depth zone are attributed to be reasons for consistent increase in catch.
- Substantial information on the spatio-temporal movement of the species on the shelf of Gujarat was generated during the study and data mapped using GIS. The participatory data generation undertaken sets a paradigm for cost effective means of augmenting information on spatial movement of fishes from small scale and artisanal fisheries around the world.

- Both sea surface temperature (SST) and chlorophyll influenced the catch rate of the species. Combined effect of SST and chlorophyll concentration to be a better predictor than individual parameters. The Generalized Additive Models (GAM) model predicted the suitable ranges of SST ($p<0.01$) as 24.5 and 27.5°C whereas that of chlorophyll ($p<0.01$) was 0.5 to 2mg/m^3.
- Information on the reproductive biology and food and feeding of the species has been brought out. The overall sex ratio was 1:2.11 with preponderance of females throughout the year. Maturing gonads were observed throughout the year except in May and June with a major peak and minor peak in spawning during February-April and October respectively. The species matured at the length of 60.7cm. Monthly GSI values indicated that the ovaries were maturing continuously from December till April.
- The diet comprised of 22 diverse groups/taxa comprising of fishes (52%), crustaceans (26%) and cephalopods (4%) along with partially digested food items (10%). A considerable quantity (8%) of plastic materials (8%) was also observed in the gut content. Diversity and composition of diet varied markedly between months with dissimilarity to the tune of 68.56%. Feeding intensity in terms of SFI varied considerably between different sizes as well as months with peaks in March and August which are established to be the pre-spawning months
- Interaction of non-tuna species and protected species like turtles and dolphins with gillnet tuna fisheries off the north-west coast of India is being reported for the first time. Discard has been nil except the incidental catches of endangered, threatened and protected (ETP) species like turtles and dolphins, which had a very negligible catch rate of 0.11 and 0.05 respectively. Unicorn leather jacket (*Aluterus monoceros*) was one of the major non-tuna species caught in the gillnets. Its dominance in the fishing grounds marked near absence of major target resources, the longtail tuna.
- Catch rates of ETPs were influenced by the depth of operation and the seasons. Turtle incidence was more in post-monsoon months while the dolphins occurred more during summer months. The turtle incidence points are in the shallow areas and dolphins occurred more in the oceanic areas. It also indicated a higher number of ETPs (3 numbers) in operations during winter and summer months, especially in oceanic areas (>200 m).
- The study demonstrated potential role of fishermen in resources management research, paving way for their proactive involvement in resources management and conservation. It pointed to awareness generation by participatory vessel based data generation enabling regular monitoring of the catches and bycatch. The study can be replicated at national scale to develop better understanding of the intricacies of gillnet fisheries for bringing in management interventions for sustaining the fishery. Integration of

electronic self-reporting by the fishermen coupled with on-board observers would enable us to have quality information and monitor the fishery at near real-time.

- Stock structure study covering Gujarat, Kerala and the Andaman & Nicobar Islands ruled out existence of more than one stock of *T. tonggol* in the wider northern Indian Ocean region along the Indian peninsula as well as the archipelagic waters of Andaman & Nicobar Islands though two haplogroups *sans* any geographic pattern were observed in the eastern AS along the west coast of India.

- The length-weight relationship for the unsexed population exhibited an isometric growth rate for *T. tonggol* (b=2.44).The asymptotic length (104 cm) and growth coefficient (K=0.27 year^{-1}) in respect of longtail tuna in the present study varied from similar studies on the species from the region as well as elsewhere. The length at which 50% of the stock became susceptible to gillnet fishery (Lc) is estimated to be 62.10 cm. The present study contradicted marginally the existing information in having a unimodal pattern of recruitment with the peak in July. The natural mortality (M), fishing mortality (F) and total mortality (Z) obtained for longtail tuna in the present study were 0.56 year^{-1}, 1.21 year^{-1} and 1.77 year^{-1}, respectively. The species became more vulnerable to the gear when it attained a fork length of 52 cm and the fishing mortality exceeded natural mortality when the fish attained a FL of 62 cm.

- The stock of longtail tuna in the northern Arabian Sea off the northwest coast of India is in relatively good state with the catches in 2016 and the average catch in the last three years remaining lower to the MSY estimates by all the models. However, diversifying the effort to areas beyond the shelves (i.e. 200m depth contour) limited to the EEZ of the country to target the oceanic tunas like the skipjack and yellowfin could be attempted to relieve the increasing fishing pressure on the continental shelf. The 40% excess effort estimated by the Analytical method can be diverted exclusively to the oceanic areas to harness the resources therein at sustainable levels. New crafts *in lieu* of the older vessels may be made resource specific with efficient preservation facilities onboard in order realise better value as well as to reduce the wastage of valuable resources due to spoilage.

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Immediate Outputs and Outcomes of the Research

Participation and presentation of Papers in International and National Foras

1. **World Ocean Science Congress 2015 (Kochi, India on 5-8 February, 2015)**: presented paper on Fishery and Spatio-Temporal distribution of the Longtail tuna,*Thunnus tonggol* off Gujarat
2. **11th Indian Fisheries and Aquaculture Forum (Kochi, India during 21-24 November, 2017):** presented a paper entitled Stock assessment of the Longtail tuna, *Thunnus tonggol* in the Eastern Arabian Sea off the North West Coast of India

Paper publications:

Peer Reviewed Journals

1. Mohammed Koya, K., P.Rohit, Abdussamad, E. M., Abdul Azeez, P., Vase, Vinaya Kumar and BharadiyaSangita, A. (2018).Reproductive biology, diet and feeding pattern of longtail tuna *Thunnustonggol* (Bleeker, 1851) in the north-eastern Arabian Sea off Gujarat, India.*Indian Journal of Fisheries*, 65 (2) 16-25.
2. Mohammed Koya, K., P. Rohit, Vinaya Kumar Vase and P. Abdul Azeez (2018) Non-target species interactions in tuna fisheries and its implications in fisheries management: Case of large-mesh gillnet fisheries along the north-west coast of India J Mar. Biol. Ass. India, 60 (1), January-June 2018
3. Mohammed Koya, K and Rohit, Prathibha and Abdussamad, E M and Vase, Vinay Kumar and Dineshbabu, A P (2018) Longtail tuna fisheries in the northern Arabian Sea off the north-west coast of India: Moving towards developing spatially explicit fisheries management strategy. Indian Journal of Fisheries, 65 (4). pp. 15-27.

Scientific Meeting Documents/Contributions

4. IOTC-2015-WPNT05-27 An overview of the tuna fishery in India with special reference to the spatial distribution and biology of *Thunnus tonggol* along the northwest region (Rohit, P., Mohammed Koya and E.M.Abdussamad (2015).
5. IOTC-2018-WPEB14-46 Non-target species interactions in tuna fisheries and its implications in fisheries management: Case of large-mesh gillnet fisheries along the north-west coast of India (Koya MK, Rohit P, Vase VK, Azeez A P (2018))

Papers /Books under Publication/Review

1. Genetic stock structure of the Longtail tuna *Thunnus tonggol* (Bleeker, 1851) fished along the coast of India
2. Preferential Habitat of the neritic tuna, *Thunnus tonggol* (Bleeker, 1851) in the Eastern Arabian Sea off the North-West Coast of India
3. ICAR-CMFRI Marine Fisheries Policy Series special publication **Management Plans for the Marine Fisheries of Gujarat**

Awards/Recognitions

The document IOTC-2018-WPEB14-46 **Non-target species interactions in tuna fisheries and its implications in fisheries management: Case of large-mesh gillnet fisheries along the north-west coast of India** was awarded the Best Presentation in the Indian Ocean Tuna Commission (IOTC) 14thWorking Party on Ecosystem and Bycatch (WPEB) held in Cape Town, South Africa Awarded with the Best Presentation.